times in delivery accumulate with increasing number of rescans for all discrete scanning techniques, especially for spot scanning. Thus, efficient rescanning requires fast lateral scanning; yet the flexibility to deliver highly modulated fields must be preserved. For this purpose, we pursue the implementation of a novel delivery technique, in which we scan the beam continuously along straight lines while quickly modulating the scan speed and/or beam current to shape the dose profile [3].

Method: Our Gantry 2 beamline provides the necessary prerequisites for this technique: (a) the extracted cyclotron current can be adjusted in less than 1 ms [4] and (b) the proton beam can be scanned with up to 2 cm/ms in lateral direction [5]. Thus, the frequency of speed and current modulation along a line can be remarkably high, which allows us to deliver both uniform and highly modulated fields. To do so, we divide each iso-energy layer in parallel lines and each of those lines in small segments (sub-mm resolution). The planned dose profile defines the scan speed and beam current of each segment. Since delivery accuracy strongly depends on the stability of the beam current, we installed a feedback system, in which the current measured in the gantry nozzle controls the output of the cyclotron in real-time.

Results: We found that scan speed modulation is favorable over beam current modulation for two reasons: (1) accuracy – we can control the scanner magnets with higher precision and shorter response time than the extracted cyclotron current – and (2) efficiency – scanning lines with a high current minimizes the overall beam-on time. Thus, the beam current is set to its maximum and lowered only in regions, where pure speed modulation fails to decrease the delivered dose sufficiently. This preserves full flexibility on dose modulation. We verified this approach by comparing highly modulated dose profiles delivered with both spot and line scanning (*cf.* figure 1). While the lateral penumbra of the line scan is slightly worse (less than + 0.1 mm on both sides), its delivery time is 20% smaller. We expect the reduction in delivery time to be even larger when rescanning multiple times.

Conclusion: Line scanning is a fast scanning technique that offers the possibility to deliver arbitrary dose distributions by quickly modulating the scan speed and beam current. Thus, we consider line scanning a well-suited technique to realize efficient and accurate rescanning of moving tumors.

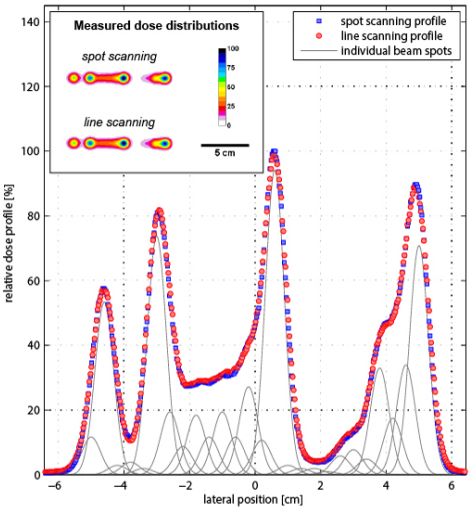

Figure 1: Comparison of a highly modulated dose distribution painted with spot and line scanning. The spot scanning profile (blue squares) was delivered by superimposing 26 individual beam spots (grey curves) with weights between 10^8 and 10^8 protons/spot. The line scanning profile (red circles) was delivered by modulating the scan speed only. The enclosed graphic shows the corresponding lateral dose distributions.

Keywords: organ motion, rescanning, dose delivery

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Criteria of spot asymmetry in proton radiotherapy pencil beam scanning – a Monte Carlo study

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Cancer treatment in hadron therapy facilities equipped with pencil beam scanning (PBS) is based on delivering each energy layer, spot by spot in the plane perpendicular to the beam axis. Uniform and robust treatment plan depends on the correct values defining horizontal and vertical spot size (*i.e.* σ_x, σ_y) introduced to the Treatment Planning System (TPS) like Eclipse (Varian). In TPS these values are, however, assumed to be constant for a given layer, moreover the influence of the spot rotation on the spot dimensions is not taken into account (Fig.). The purpose of this study was to propose criteria of spot asymmetry within which target dose conformity is preserved.

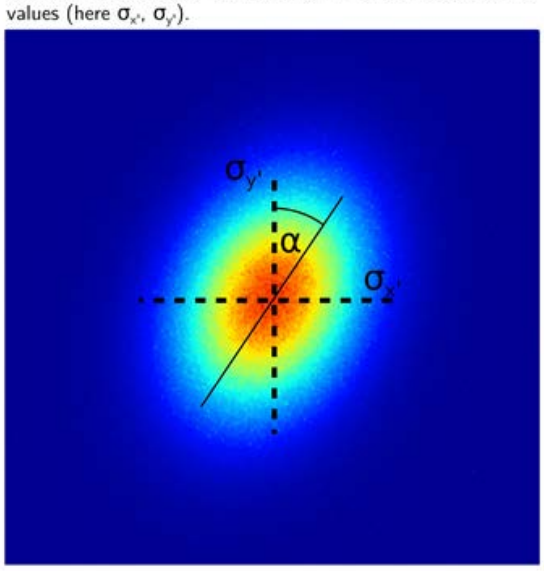
In the Eclipse for Proton TPS a conformal field of 3 x 3 x 3 cm^3 was planned to cover the whole target volume with at least 95% dose. A dedicated tool was developed to convert the treatment plan into the simulation input file. Simulations were performed with FLUKA transport code [1,2] with uncertainty level kept below 1%, by using computational PL-Grid Infrastructure.

Dedicated beam model for proton scanning beam in the gantry-1 room at the Bronowice Cyclotron Centre (IFJ Kraków) was used. Preserving the 2D Gaussian spot shape (volume integral) and spot weight, spot σ up to 50% and spot rotation up to 45° were investigated. 1D and 2D analysis of dose distribution was carried out.

For asymmetrical spots field width differences were observed together with larger lateral penumbra (the factor of 1.5 obtained for maximal spot asymmetry), which resulted in target volume decrease [3]. Perturbed field flatness did not exceed the accepted level of 5% difference. By spot rotation implemented to all spots whole target region skewness was observed.

The tool for treatment plan conversion into a Monte Carlo input file has been created to consider spot deformation indistinct to the TPS dose calculation. Observed field dose non-uniformity may be the origin of hot and cold spots inside and outside the target volume. Considered spot asymmetry criteria allow to preserve optimal target dose distribution with regard to the spot size changes. As such spot deformation can differ for different gantry angles, accurate gantry-angle-dependent spot shape measurements with 2D detectors such as films or 2D foils are considered.

Spot sizes are obtained from the horizontal and vertical profiles, not taking into account the influence of the spot rotation by the angle α, resulting in different spot sigma values (here $\sigma_{x'}$, $\sigma_{y'}$).



Keywords: proton radiotherapy, spot asymmetry, Monte Carlo

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^{191}Os – revival of an out-of-favor radionuclide?

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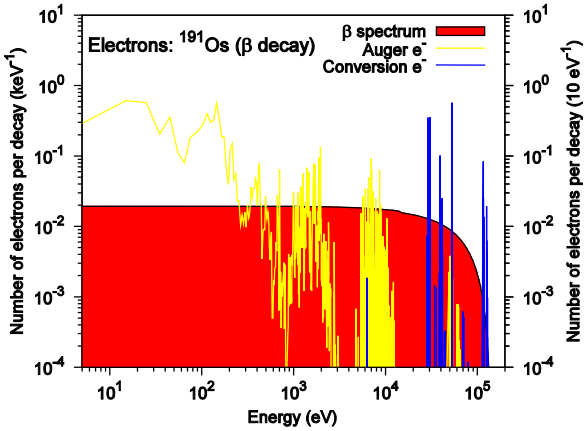
Purpose: Novel osmium anticancer drugs are under evaluation that promise superior properties with respect to traditional Pt based drugs [1]. Even selective action against cancer stem cells has been reported [2]. Radiotracer and nuclear medicine techniques could help in the development and application of these drugs. ^{191}Os is an osmium radioisotope well suited for this purpose with excellent properties for imaging and therapy. We discuss calculated Auger electron spectra, production methods and prospects of applications of ^{191}Os.

Methods: ^{191}Os ($T_{1/2}$=15.4 d) decays to short-lived ($T_{1/2}$=4.9 s) ^{191m}Ir that emits 129 keV γ rays (26.5% intensity) well suited for SPECT imaging. In the past ^{191}Os/^{191m}Ir generators [3] were used to provide ^{191m}Ir for first pass radionuclide angiocardiography [4] or studies of renal blood flow [5], but no direct use of ^{191}Os has been reported so far. Among all known β-emitters with days to weeks half-life ^{191}Os sticks up with the lowest β decay energy of only 38 keV on average (114 keV maximum), corresponding to a range of about one cell diameter. This β radiation is supplemented by abundant emission of short-range conversion and Auger electrons (< 60 keV). Consequently ^{191}Os has also potential as therapeutic isotope. The Auger electron spectrum of this decay was calculated using the methodology described in Ref. [6].

Results: The figure shows the calculated electron energy spectrum in the β^- decay of ^{191}Os (red, left scale) and in the internal transition decay of ^{191m}Ir (blue and yellow, right scale).



Upon β^- decay of ^{191}Os the nuclear recoil of ^{191m}Ir is <0.4 eV, thus avoiding breakage of chemical bonds and uncontrolled translocation of ^{191m}Ir, provided the chemical valency change is tolerated.

Direct production by ^{190}Os(n,γ)^{191}Os in a high thermal neutron flux of $1.5{\cdot}10^{15}$ n.cm^{-2}s^{-1} in ILL's high flux reactor [7] reaches specific activities of ≈10 GBq/mg (≈2 MBq/μmol) after 5 days of irradiation.

For Os drug dosages similar to cisplatin dosage this specific activity is by far sufficient for preclinical and clinical SPECT imaging. Even shorter irradiation times can be used to minimize co-produced activities (^{192}Ir, etc.).

Conclusions: Reactor-produced ^{191}Os has great potential as radiotracer for in vitro studies of sub-cellular distribution of Os based drugs, for preclinical and clinical in vivo studies of pharmacokinetics of Os based drugs and eventually even for combined radionuclide-chemotherapy against particularly resistant tumors.

Keywords: osmium-based chemotherapy drugs, SPECT, Auger emitter

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A dose response analysis of the patients treated with Boron Neutron Capture Therapy (BNCT) in Finland in 1999 to 2011

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In 1999 to 2011, 249 cancer patients received boronophenylalanine (BPA)-mediated boron neutron capture therapy (BNCT) in Finland. Over one hundred of these patients were treated within the context of clinical trials. The purpose of the trials was to investigate the efficacy and safety of BNCT in the treatment of malignant gliomas (newly diagnosed or gliomas that progressed after surgery and radiotherapy) [1,2], and inoperable head-and-neck cancers that had recurred locally after external radiotherapy [3,4].

In BNCT, the absorbed radiation dose results from four main components: 1) the therapeutically desired high-LET